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COLUMN AND PLATE COMPRESSIVE STRENGTHS

OF AIRCRAFT STRUCTURAL MATERIALS

17S-T ALUMINUM-ALLOY SHEET

By George J. Heimerl and J. Albert Roy

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Langley Field, Va.

NACA

WASHINGTON

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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COLUMN AND PLATE COMPRESSIVE STRENGTHS OF AIRCRAFT STRUCTURAL MATERIALS

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SUMMARY

Column and plate compressive strengths of 17S-T aluminum-alloy sheet were determined both within and beyond the elastic range from tests of thin-strip columns and from local-instability tests of formed Z- and channel-section columns. These tests are part of an extensive research investigation to provide data on the structural strengths of various aircraft materials. Results are presented in the form of curves and charts that may be used in the design and analysis of aircraft structures.

INTRODUCTION

Column and plate members in an aircraft structure are the basic elements that fail by instability. For the design of low-weight, structurally efficient aircraft, the strength of these elements must be known for the various aircraft materials. An extensive research investigation has therefore been undertaken at the Langley Memorial Aeronautical Laboratory on the column and plate compressive strengths of a number of the alloys available for use in aircraft structures. That part of the investigation for 24S-T aluminum-alloy sheet has already been completed and is given in reference 1.

The results of tests to determine the column and plate compressive strengths of 17S-T aluminum-alloy sheet are given herein.

[redacted]

SYMBOLS

L length of column

ρ radius of gyration

c fixity coefficient used in Euler column formula

$\frac{L}{\rho\sqrt{c}}$ effective slenderness ratio of thin-strip column

b_F width of flange of Z- or channel section (see fig. 1)

b_W width of web of Z- or channel section (see fig. 1)

r inside radius of bend of Z- or channel section (see fig. 1)

t thickness of plate

k_W nondimensional coefficient used with b_W and t in plate-buckling formula (see fig. 2 and reference 2)

E_c modulus of elasticity in compression, taken as 10,600 ksi for 17S-T aluminum alloy

τ nondimensional coefficient (The value of τ is so determined that when the effective modulus τE_c is substituted for E_c in the equation for elastic buckling of columns, the computed critical stress agrees with the experimentally observed value. The coefficient τ is equal to unity within the elastic range and decreases with increasing stress beyond the elastic range.)

η nondimensional coefficient for plates corresponding to τ for columns

μ Poisson's ratio, taken as 0.3 for 17S-T aluminum alloy

σ_{cr} critical compressive stress

$\bar{\sigma}_{max}$ average compressive stress at maximum load

σ_{cy} compressive yield stress

METHODS OF TESTING AND ANALYSIS

All tests were made in hydraulic testing machines accurate to within three-fourths of 1 percent. The ends of the stress-strain specimens and the columns were ground flat and square.

The methods of testing and analysis developed for this research program are described in reference 1 and may be briefly summarized as follows:

The compressive stress-strain curves for the flat sheet, which identify the material for correlation with its column and plate compressive strengths, were obtained from tests of single-thickness specimens in a compression fixture of the Mongtomery-Templin type that provides lateral support through closely spaced rollers. For the bent material in the corners of the formed Z- and channel sections, compression specimens were cut from the corner portion and tested in a specially designed fixture that provided continuous support along the length.

The column strength and the associated effective column modulus were obtained by the use of the method presented in reference 3, which consists in tests of thin-strip columns of the material with the ends clamped in fixtures that provide a high degree of end restraint. The fixtures used have been improved and the method of analysis has been modified since publication of reference 3. The method now used results in a column curve representative of nearly perfect column specimens. In addition, the method now takes into account the fact that columns of the dimensions tested are actually plates with two free edges.

The plate compressive strength of the material was obtained from compression tests of formed Z- and channel-section columns so proportioned as to develop local instability, that is, instability of the plate elements of which the columns are comprised. (See fig. 3.) The lengths of the columns were chosen in accordance with the principles set forth in reference 4. The columns were tested with the flat ends bearing directly against the testing-machine heads. In these local-instability tests, measurements were taken of the cross-sectional distortion, and the critical stress was determined as the stress at the point near the top of the knee of the stress-distortion curve at which a marked increase in distortion first occurred with small increase in stress.

RESULTS AND DISCUSSION

Compressive Stress-Strain Curves

Compressive stress-strain curves for the 17S-T aluminum-alloy flat sheet used are given in figure 4 for both directions of grain. The compressive yield stress for the cross-grain direction averages about 11 percent higher than that for the with-grain direction.

When the flat sheet material is bent to an inside radius of 3t to form a Z- or channel section, the cold work done on the material evidently raises the compressive yield stress for the corner to a higher value than that for the flat web or flange. (See fig. 5.) The increase in the compressive yield stress at the corner is indicated to be about 23 percent for the with-grain and about 15 percent for the cross-grain direction. Because about 40 percent of the area of the curved corner specimens represented flat material along the edges of the specimen, for which the compressive yield stress is less than that for the curved portion, the actual increase in compressive yield stress for the corner portion may be somewhat greator than the increase indicated in figure 5.

The Z-, channel, and thin-strip columns to which a particular stress-strain curve applies are indicated in table 1, together with the value of the compressive yield stress σ_{cy} for that stress-strain curve. These values of σ_{cy} average about 41 ksi for the with-grain direction. The modulus of elasticity in compression was taken as 10,600 ksi, the present accepted value for 17S-T aluminum alloy.

Values of the compressive yield stress of the material used for these tests are somewhat higher than the typical values given by the Aluminum Company of America for 17S-T aluminum-alloy sheet. Because the compressive yield stress of this material may vary appreciably, the data and charts of this report should not be used for design purposes for material having values of compressive yield stress appreciably different from those reported herein unless a suitable method is devised for adjusting test results for variation in material properties.

Column and Plate Compressive Strength

The results of the column and local-instability tests for the 17S-T aluminum-alloy sheet are summarized herein. A discussion of the basic relationships is given in reference 1.

Column strength.- The column curves of figure 6 show the results of the thin-strip-column tests for both directions of grain. The reduction of the effective modulus of elasticity τE_c with stress for columns is indicated by the variation of τ with stress shown in figure 7.

Plate compressive strength.- The results of the local-instability tests of the formed Z- and channel-section columns, used to determine the plate compressive strength, are given in tables 2 and 3, respectively.

The plate-buckling curve, which is analogous to the column curve of figure 6, is shown in figure 8. The reduction of the effective modulus of elasticity ηE_c with stress for plates is indicated by the variation of η with stress, which is shown together with the variation of τ in figure 7. The crossing of the τ- and η-curves shown in figure 7 occurs because the formed columns apparently had an appreciable degree of imperfection, which resulted in the deviation of the η-curve from unity at a lower stress than that at which the τ-curve, representative of nearly perfect columns, deviated from unity.

The variation of the actual critical stress σ_{cr} with the theoretical critical stress σ_{cr}/η computed for elastic buckling by means of the formula and curve of figure 2 is shown in figure 9.

In order to illustrate the difference between the critical stress σ_{cr} and the average stress at maximum load $\bar{\sigma}_{max}$, the variation of σ_{cr} with $\sigma_{cr}/\bar{\sigma}_{max}$ is shown in figure 10. Because values of $\bar{\sigma}_{max}$ may be required in strength calculations, the variation of $\bar{\sigma}_{max}$ with σ_{cr}/η is indicated in figure 11. The

effect of grain direction on the plate compressive strength is shown in figure 12.

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2. Kroll, W. D., Fisher, Gordon P., and Heimerl, George J.: Charts for Calculation of the Critical Stress for Local Instability of Columns with I-, Z-, Channel, and Rectangular-Tube Section. NACA ARR No. 3K04, 1943.

3. Lundquist, Eugene E., Rossman, Carl A., and Houbolt, John C.: A Method for Determining the Column Curve from Tests of Columns with Equal Restraints against Rotation on the Ends. NACA TN No. 903, 1943.

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TABLE 1

COMPRESSIVE PROPERTIES OF 17S-T ALUMINUM-ALLOY SHEET

[E_c = 10,600 ksi]

Columns to which stress-strain curves apply			Stress-strain curve (fig. 4)	Compressive yield stress, σ_{cy} (ksi)	
Type	Direction of loading	Designation (See tables 2 and 3)		With grain	Cross grain
Thin strip	With grain and cross grain	All	A	40.9	45.3
Z	With grain	All except 5a to 5c	B	41.5	46.5
		5a to 5c	C	41.8	45.9
Z	Cross grain	All	D	40.2	45.6
Channel	With grain	All	B	41.5	46.5
Channel	Cross grain	All	D	40.2	45.6

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TABLE 2

DIMENSIONS AND TEST RESULTS FOR FORMED Z-SECTION COLUMNS THAT DEVELOP LOCAL INSTABILITY

Column	t (in.)	b_W (in.)	b_F (in.)	L (in.)	$\frac{L}{b_W}$	$\frac{b_W}{t}$	$\frac{b_F}{b_W}$	k_W (a)	$\frac{b_W}{t}\sqrt{\frac{12(1-\mu^2)}{k_W}}$	$\frac{\sigma_{cr}}{\eta}$ (ksi) (b)	σ_{cr} (ksi)	$\bar{\sigma}_{max}$ (ksi)	$\frac{\sigma_{cr}}{\bar{\sigma}_{max}}$
						With grain							
1a	0.124	2.50	1.37	12.10	4.9	20.21	0.548	2.54	41.9	60.2	44.2	46.2	0.957
1b	.124	2.50	1.37	12.10	4.8	20.20	.548	2.54	41.9	60.2	43.6	46.3	.942
1c	.124	2.51	1.37	12.11	4.8	20.29	.547	2.55	42.0	59.9	44.3	46.6	.951
2a	.123	2.51	1.74	13.75	5.5	20.42	.693	1.73	51.3	40.1	35.1	36.8	.954
2b	.124	2.50	1.74	13.72	5.5	20.21	.695	1.71	51.1	40.5	35.5	37.5	.947
2c	.122	2.51	1.74	13.75	5.5	20.60	.692	1.73	51.1	39.5	33.7	36.4	.926
3a	.123	3.13	1.24	13.26	4.2	25.44	.396	3.77	43.3	56.3	43.4	44.7	.971
3b	.123	3.13	1.23	13.23	4.2	25.37	.394	3.79	43.1	56.9	43.0	44.5	.966
3c	.124	3.13	1.24	13.23	4.2	25.23	.396	3.77	43.0	57.2	43.2	44.3	.975
4a	.124	3.12	1.71	15.19	4.9	25.17	.547	2.55	52.1	39.0	31.6	34.9	.905
4b	.123	3.13	1.71	15.19	4.9	25.42	.547	2.55	52.6	38.2	32.8	34.8	.943
4c	.124	3.13	1.71	15.20	4.9	25.32	.546	2.55	52.4	38.5	32.7	35.3	.926
5a	.124	3.13	2.18	17.20	5.5	25.25	.697	1.70	64.0	25.7	26.1	31.8	.821
5b	.123	3.14	2.21	17.20	5.5	25.57	.703	1.68	65.2	24.8	25.5	31.4	.812
5c	.123	3.14	2.22	17.21	5.5	25.57	.706	1.68	65.2	24.8	25.1	32.0	.784
6a	.124	3.87	1.56	16.50	4.3	31.15	.403	3.72	53.4	37.0	32.0	33.7	.950
6b	.124	3.87	1.56	16.50	4.3	31.19	.402	3.73	53.4	37.0	32.2	34.3	.939
6c	.124	3.86	1.56	16.49	4.3	31.26	.403	3.72	53.5	36.8	31.4	32.9	.954
7a	.123	3.91	2.14	18.80	4.8	31.84	.549	2.53	66.2	24.1	24.3	29.4	.827
7b	.123	3.90	2.14	18.82	4.8	31.65	.549	2.53	65.8	24.4	24.0	29.7	.808
7c	.123	3.90	2.15	18.82	4.8	31.72	.550	2.52	66.0	24.2	24.0	29.3	.819
8a	.124	3.90	2.73	21.23	5.4	31.59	.699	1.70	80.0	16.5	16.1	27.3	.590
8b	.123	3.90	2.71	21.09	5.4	31.64	.695	1.72	79.7	16.7	16.6	27.1	.613
8c	.123	3.90	2.72	20.96	5.4	31.68	.697	1.71	80.0	16.5	15.3	27.1	.565
						Cross grain							
1a	0.123	2.19	1.39	9.95	4.6	17.72	0.634	2.01	41.3	61.9	46.8	48.5	0.966
1b	.123	2.19	1.39	9.97	4.6	17.78	.635	2.00	41.5	61.2	45.1	48.1	.938
1c	.123	2.18	1.39	9.80	4.5	17.68	.636	1.99	41.4	61.6	44.4	46.9	.946
2a	.123	2.55	1.53	12.80	5.0	20.71	.599	2.20	46.1	49.6	40.9	42.8	.956
2b	.123	2.55	1.52	12.81	5.0	20.71	.596	2.22	45.9	50.1	42.1	42.4	.993
2c	.123	2.56	1.53	12.82	5.0	20.72	.600	2.20	46.2	49.6	42.7	43.3	.986
3a	.123	3.09	1.83	15.41	5.0	25.03	.594	2.23	55.4	34.4	32.9	35.1	.937
3b	.123	3.09	1.84	15.41	5.0	25.08	.596	2.22	55.6	34.1	33.0	35.2	.938
3c	.123	3.09	1.84	15.42	5.0	25.01	.596	2.22	55.5	34.3	33.4	35.4	.944
4a	.123	4.03	2.42	20.00	5.0	32.74	.601	2.19	73.1	19.8	20.0	28.3	.707
4b	.124	4.03	2.42	20.00	5.0	32.62	.601	2.19	72.8	19.9	20.2	28.4	.711
4c	.123	4.03	2.42	20.00	5.0	32.70	.601	2.19	73.02	19.8	20.1	28.1	.715

[a] For values of k_W, see figure 2.

[b] $\frac{\sigma_{cr}}{\eta} = \frac{k_W \pi^2 E_c t^2}{12(1-\mu^2){b_W}^2}$, where E_c = 10,600 ksi and μ = 0.3.

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TABLE 3

DIMENSIONS AND TEST RESULTS FOR FORMED CHANNEL-SECTION COLUMNS THAT DEVELOP LOCAL INSTABILITY

Column	t (in.)	b_W (in.)	b_F (in.)	L (in.)	$\frac{L}{b_W}$	$\frac{b_W}{t}$	$\frac{b_F}{b_W}$	k_W (a)	$\frac{b_W}{t}\sqrt{\frac{12(1-\mu^2)}{k_W}}$	$\frac{\sigma_{cr}}{\eta}$ (ksi) (b)	σ_{cr} (ksi)	$\bar{\sigma}_{max}$ (ksi)	$\frac{\sigma_{cr}}{\bar{\sigma}_{max}}$
With grain													
1a	0.122	2.51	0.99	10.61	4.2	20.60	0.394	3.78	35.0	86.1	47.6	51.0	0.933
1b	.122	2.51	.99	10.60	4.2	20.60	.394	3.78	35.0	86.1	48.0	51.6	.931
2a	.123	2.51	1.37	12.04	4.8	20.42	.544	2.57	42.1	59.6	41.7	43.4	.961
2b	.123	2.51	1.37	12.02	4.8	20.35	.547	2.54	42.2	59.4	43.1	45.1	.956
2c	.123	2.51	1.37	12.10	4.8	20.45	.548	2.53	42.5	58.5	42.6	44.9	.949
3a	.124	2.48	1.75	13.75	5.6	19.97	.708	1.67	51.1	40.5	33.1	36.0	.919
3b	.123	2.50	1.75	13.75	5.5	20.30	.699	1.70	51.5	39.9	33.9	36.2	.936
4a	.123	3.13	1.24	13.26	4.2	25.42	.395	3.78	43.2	56.5	41.9	44.0	.952
4b	.123	3.13	1.24	13.25	4.2	25.53	.396	3.77	43.5	55.9	40.6	42.9	.946
4c	.124	3.13	1.24	13.27	4.3	25.21	.396	3.77	42.9	57.3	43.1	44.3	.973
5a	.124	3.14	1.67	15.18	4.8	25.29	.531	2.66	51.3	40.2	32.4	34.8	.931
5b	.124	3.13	1.70	15.20	4.9	25.23	.545	2.56	52.1	38.9	34.4	35.5	.969
5c	.123	3.13	1.69	15.19	4.9	25.53	.541	2.59	52.4	38.5	33.3	35.1	.949
6a	.124	3.14	2.17	17.20	5.5	25.37	.691	1.73	63.7	25.9	26.3	31.2	.843
6b	.123	3.15	2.18	17.22	5.5	25.56	.691	1.73	64.2	25.6	25.1	31.3	.802
7a	.123	3.88	1.54	16.50	4.3	31.56	.397	3.76	53.8	36.5	32.0	33.7	.950
7b	.125	3.88	1.56	16.52	4.3	31.13	.401	3.74	53.2	37.3	32.8	34.3	.956
7c	.123	3.89	1.54	16.52	4.3	31.58	.398	3.76	53.8	36.4	33.7	34.7	.971
8a	.123	3.91	2.14	18.80	4.8	31.74	.547	2.54	65.8	24.4	24.9	29.3	.850
8b	.123	3.91	2.13	18.81	4.8	31.76	.546	2.55	65.7	24.4	24.3	29.2	.832
8c	.122	3.90	2.14	18.80	4.8	31.99	.548	2.53	66.5	23.9	23.4	29.8	.735
9a	.122	3.88	2.72	21.31	5.5	31.96	.700	1.70	80.9	16.0	17.2	26.4	.652
9b	.124	3.89	2.72	21.21	5.5	31.51	.698	1.71	79.6	16.7	15.7	26.6	.590
9c	.124	3.91	2.72	21.27	5.5	31.63	.697	1.71	79.8	16.6	16.5	26.9	.613
Cross grain													
1a	0.123	2.22	1.39	10.00	4.5	17.98	0.628	2.03	41.7	60.8	45.6	48.5	0.940
1b	.123	2.23	1.39	9.97	4.5	18.11	.625	2.05	41.8	60.5	46.1	48.1	.958
1c	.123	2.22	1.39	9.97	4.5	17.96	.626	2.05	41.5	61.5	47.3	48.7	.973
2a	.123	2.54	1.53	12.82	5.0	20.60	.601	2.19	46.0	49.9	42.7	43.8	.975
2b	.123	2.55	1.53	12.81	5.0	20.71	.599	2.20	46.1	49.6	40.4	42.5	.953
2c	.123	2.55	1.53	12.81	5.0	20.71	.600	2.19	46.2	49.4	40.0	43.1	.929
3	.123	3.10	1.84	15.41	5.0	25.11	.593	2.23	55.6	34.2	32.6	35.4	.921
4a	.123	4.02	2.43	20.00	5.0	32.63	.605	2.16	73.4	19.6	17.1	28.7	.596
4b	.123	4.03	2.43	20.00	5.0	32.92	.602	2.19	73.5	19.6	18.3	28.8	.635

[a]For values of k_W, see figure 2.

[b] $\frac{\sigma_{cr}}{\eta} = \frac{k_W \pi^2 E_c t^2}{12(1-\mu^2){b_W}^2}$, where $E_c = 10,600$ ksi and $\mu = 0.3$.

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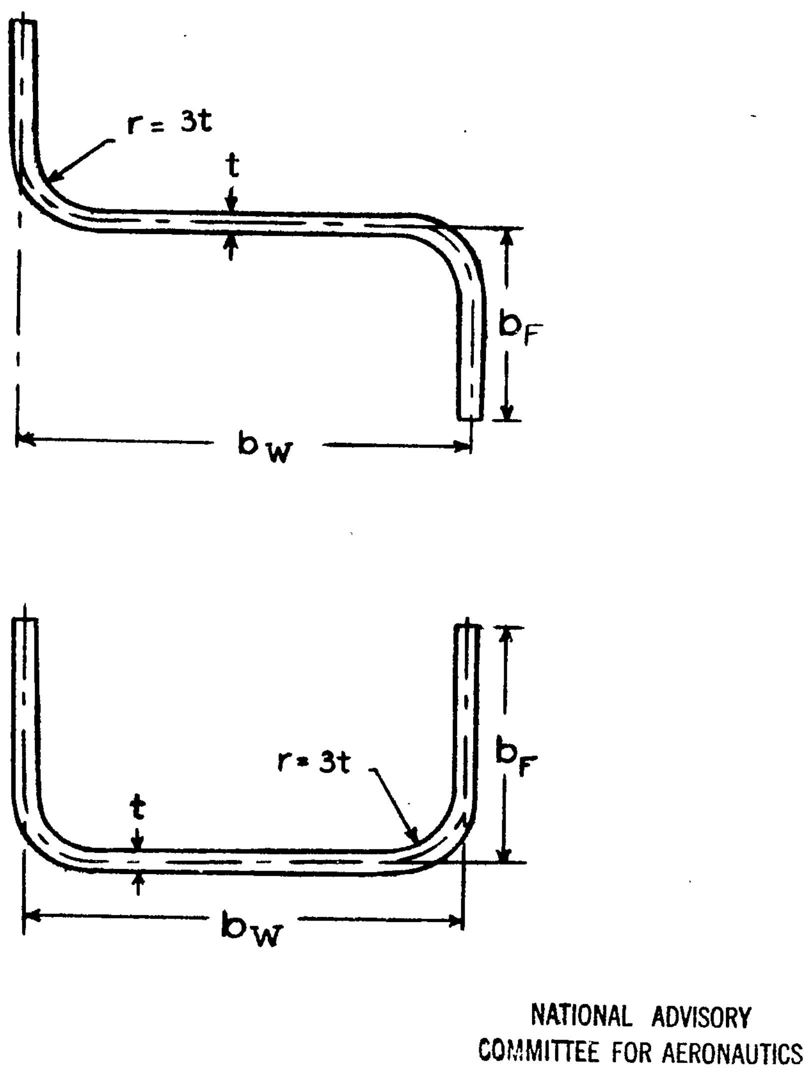


Figure 1.- Cross sections of Z-and channel-section columns.

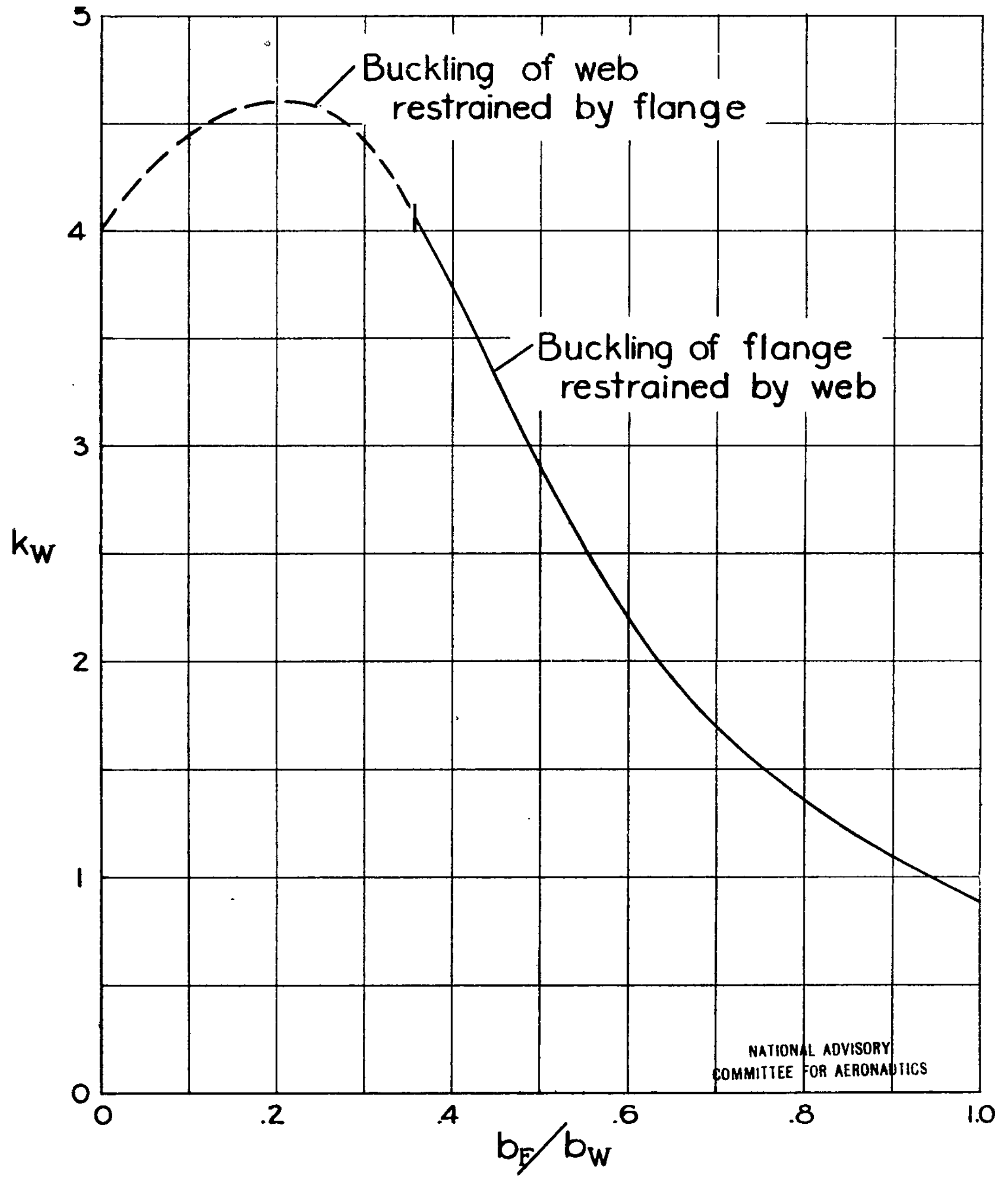


Figure 2.-Values of k_W for Z- and channel-section columns of uniform thickness (from reference 2).

$$\frac{\sigma_{cr}}{\eta} = \frac{k_W \pi^2 E_c t^2}{12(1-\mu^2){b_W}^2}$$

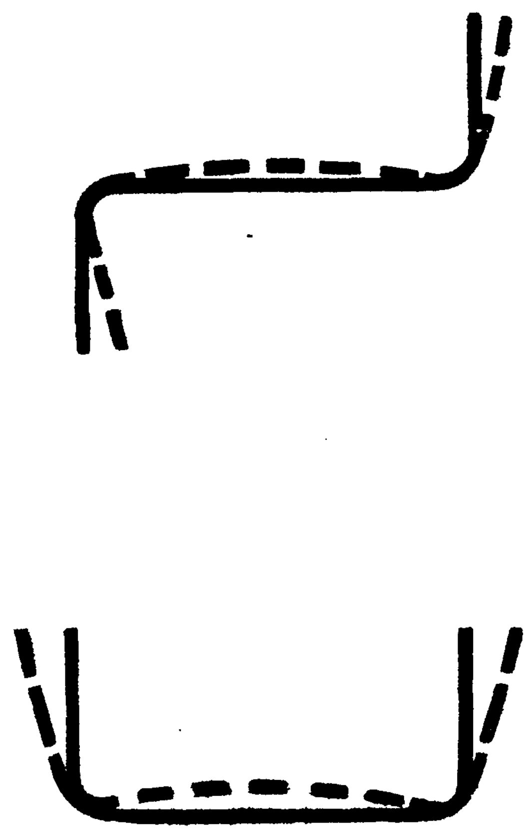


Figure 3.- Typical cross-sectional distortion of columns that develop local instability.

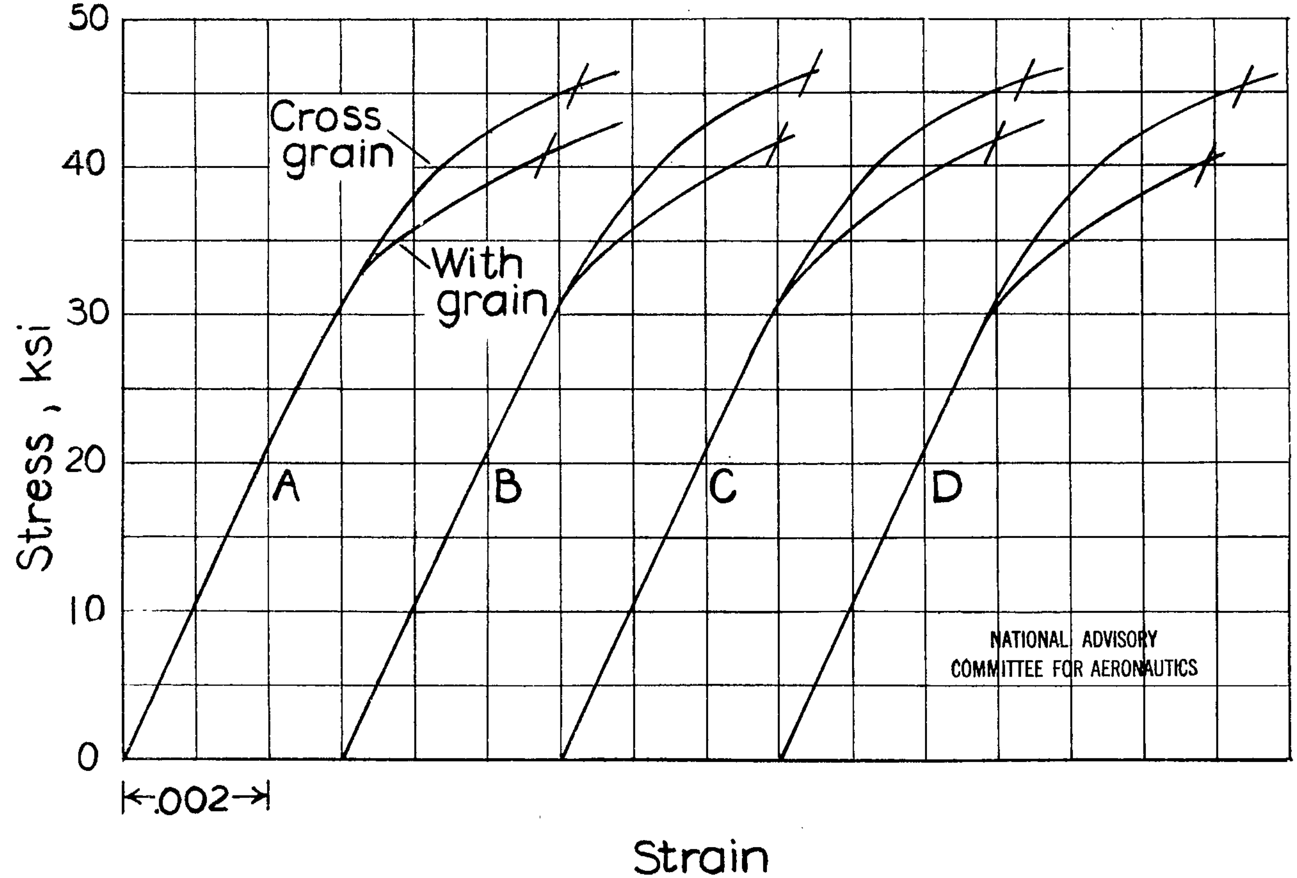


Figure 4. - Compressive stress-strain curves for 17S-T aluminum-alloy flat sheet. (Curves A, B, C, D, are identified in table 1.)

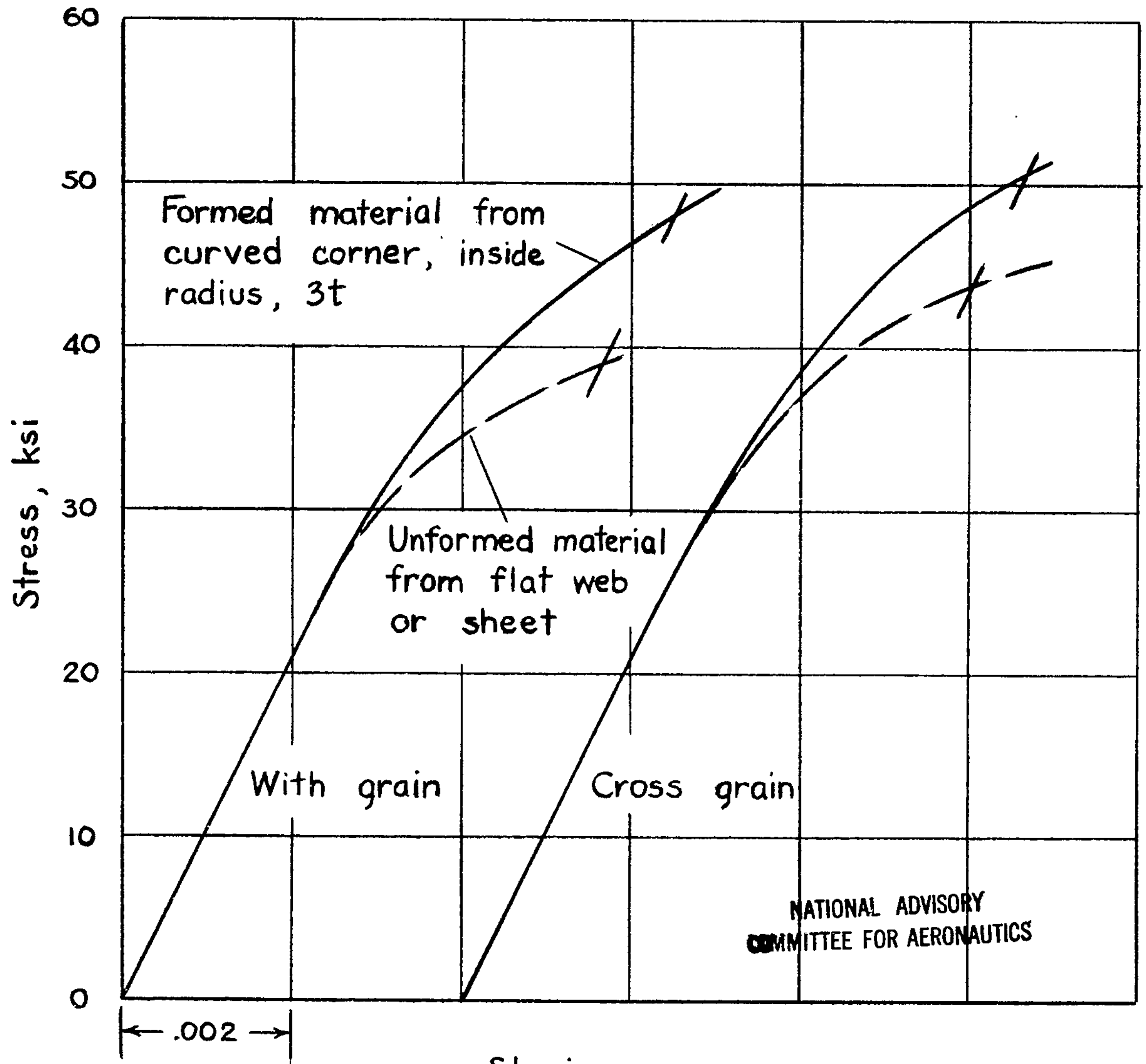


Figure 5. - Effect of forming on compressive stress-strain curves for 17S-T aluminum-alloy Z-section. t = 0.125 inches.

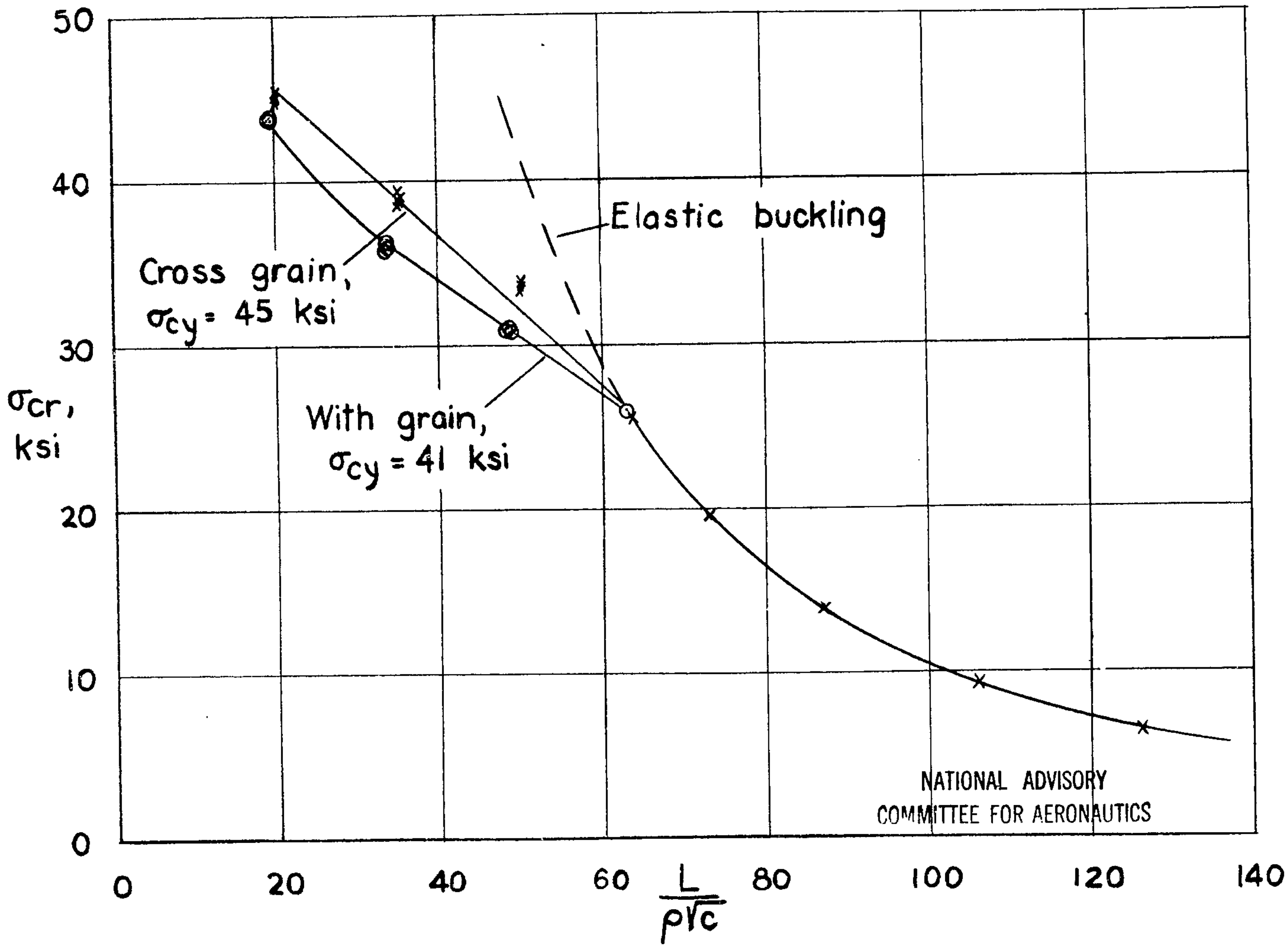


Figure 6. - Column curves for 17S-T aluminum-alloy sheet.

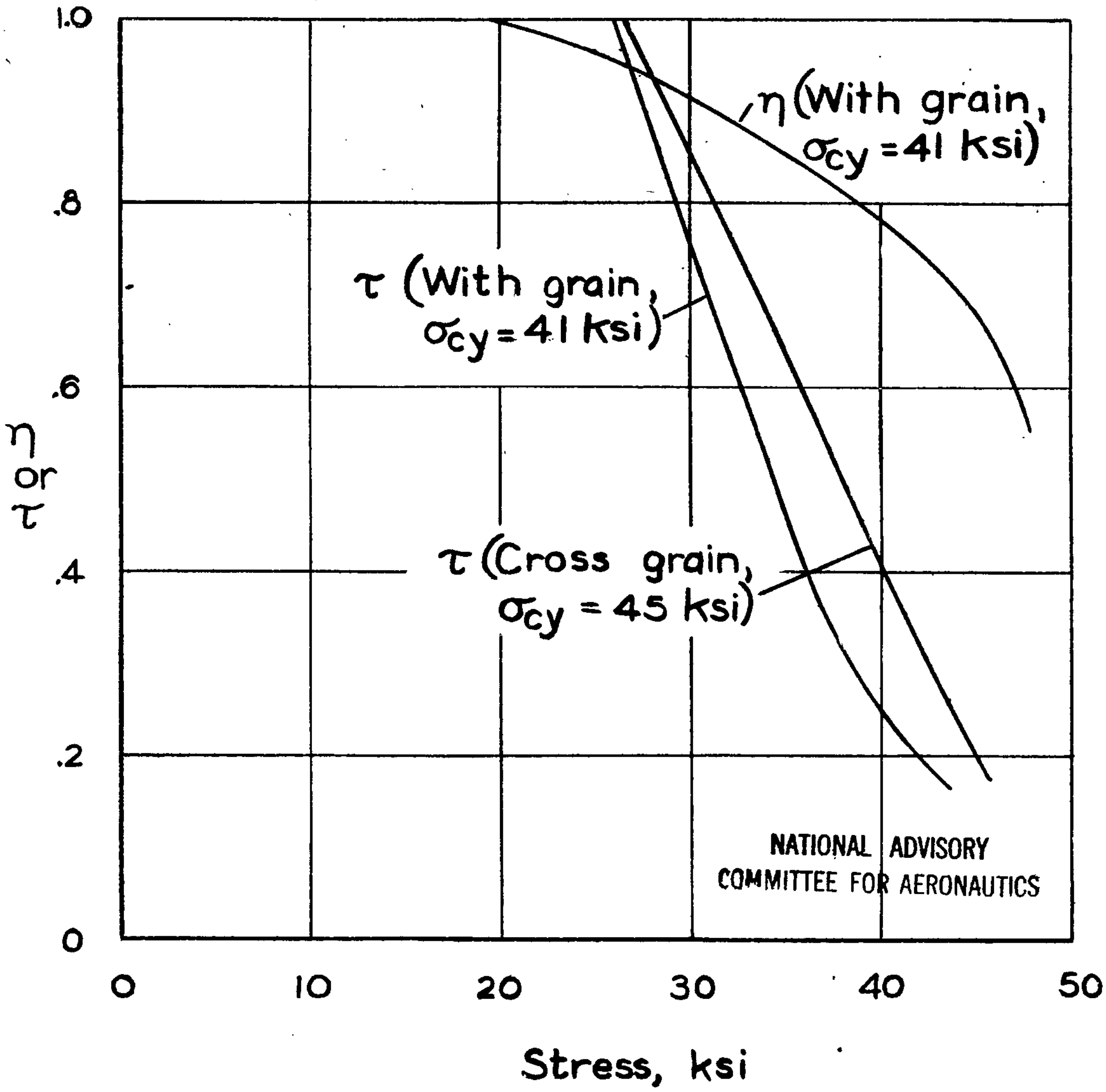


Figure 7.- Variation of η and τ with stress for 17S-T aluminum-alloy sheet (η obtained from tests of formed columns).

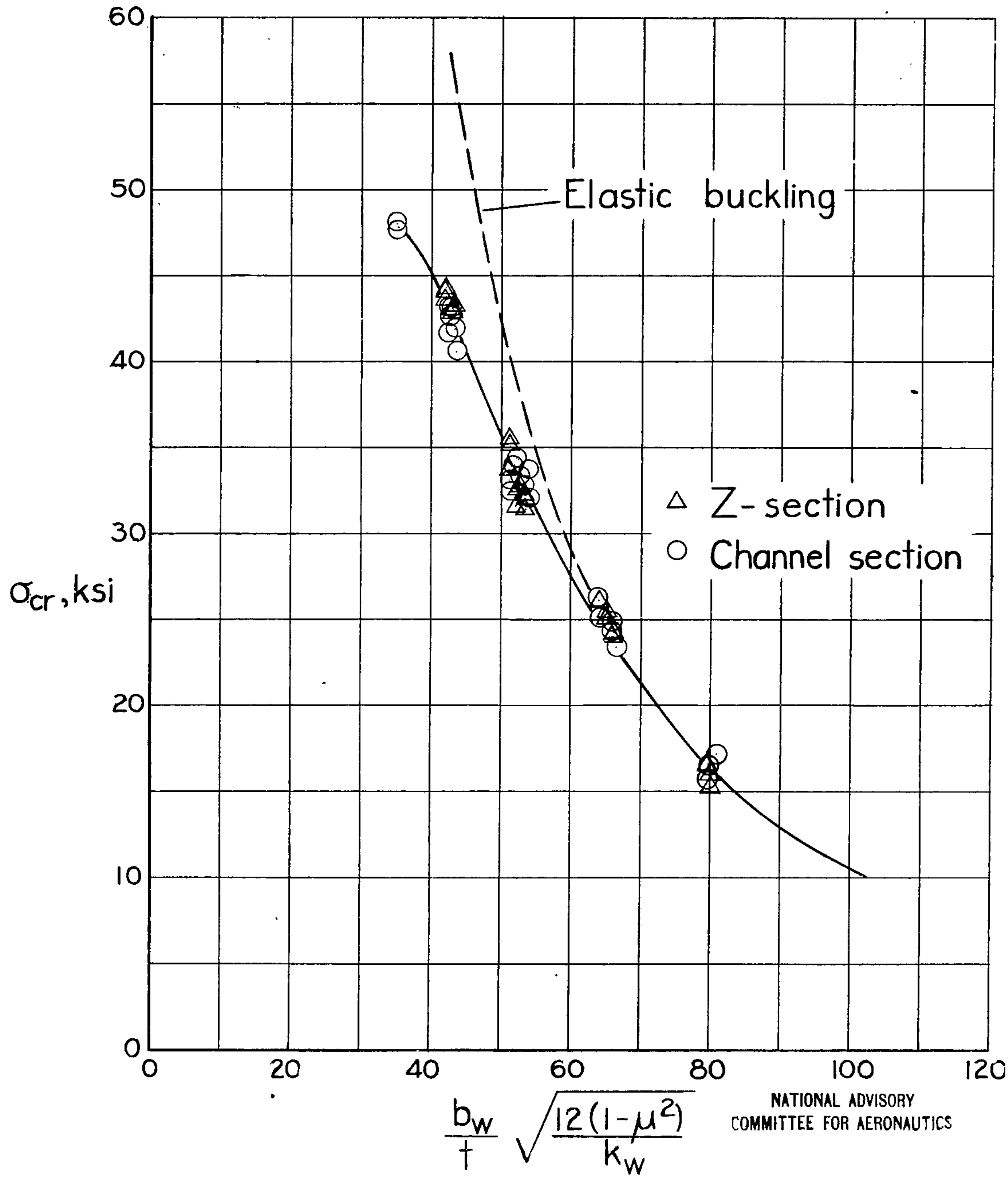


Figure 8.- Plate-buckling curve for 17S-T aluminum-alloy sheet loaded in the with-grain direction. Obtained from tests of formed columns. σ_{cy} = 41 ksi.

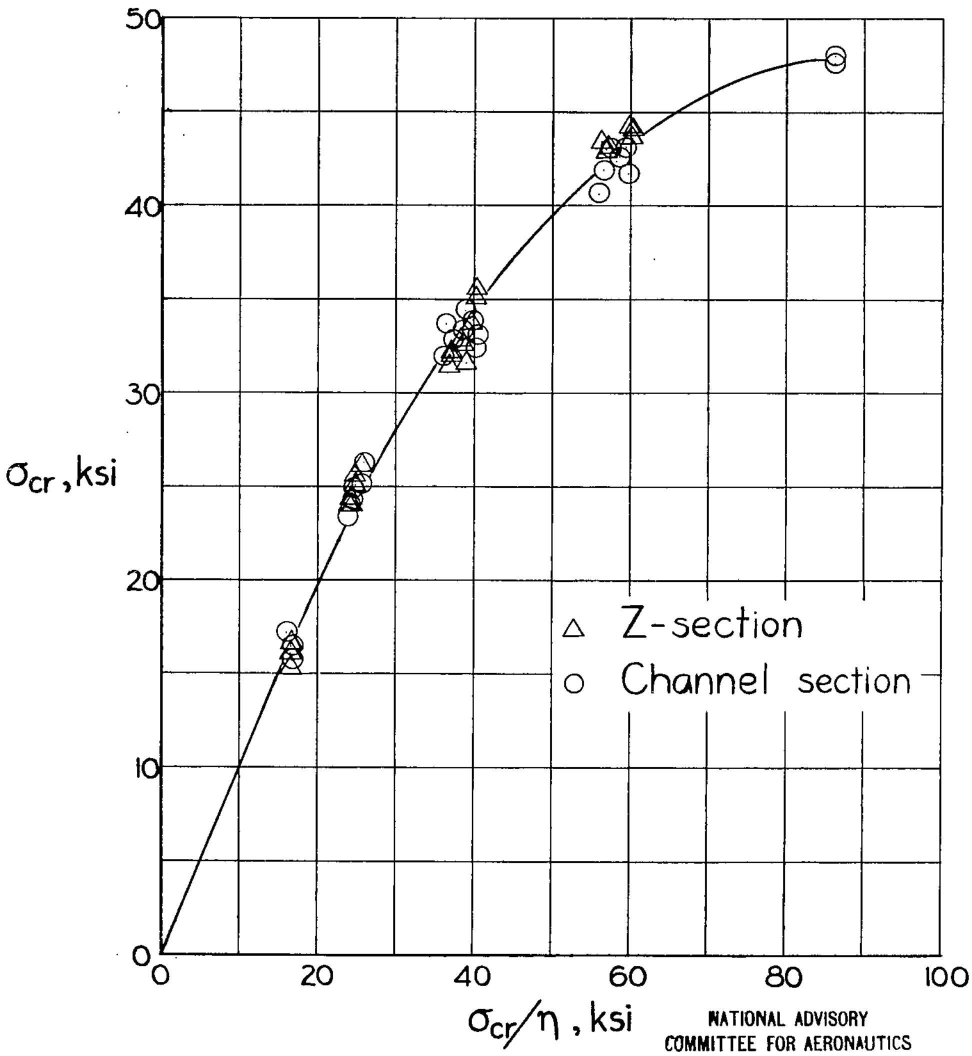
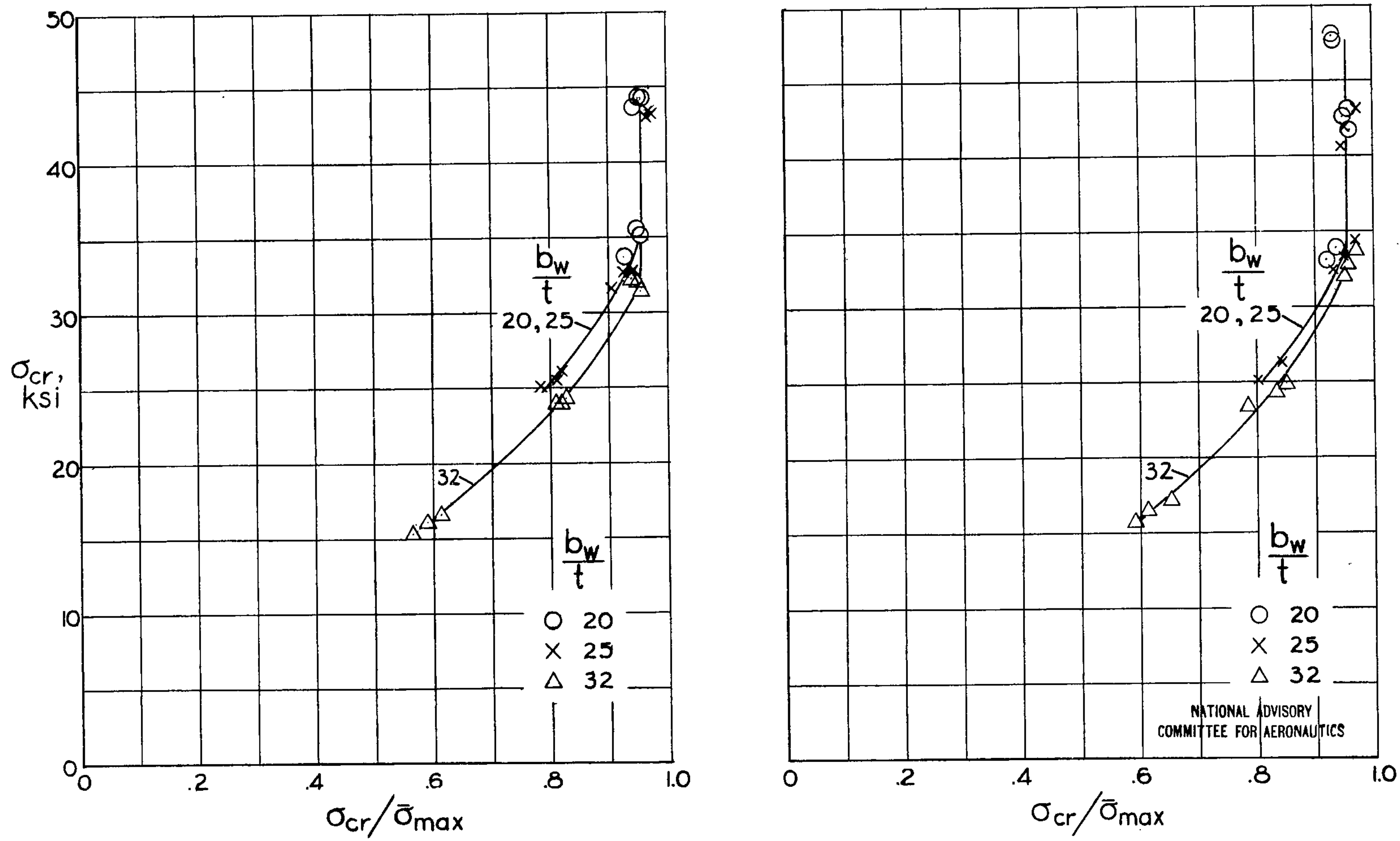


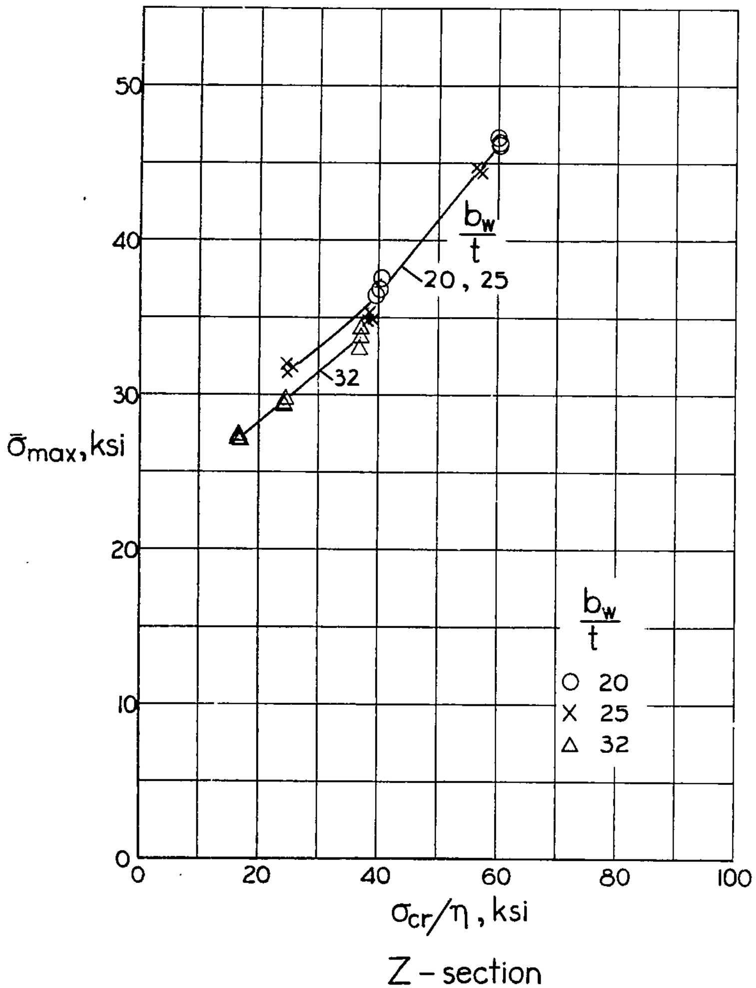
Figure 9. - Variation of σ_{cr} with σ_{cr}/η for plates of 17S-T aluminum-alloy sheet loaded in the with-grain direction. Obtained from tests of formed columns. $\sigma_{cy} = 41$ ksi.



Z – section

Channel section

Figure 10.- Variation of σ_{cr} with $\sigma_{cr}/\bar{\sigma}_{max}$ for formed 17S-T aluminum-alloy columns loaded in the with-grain direction. $\sigma_{cy} = 41$ ksi .



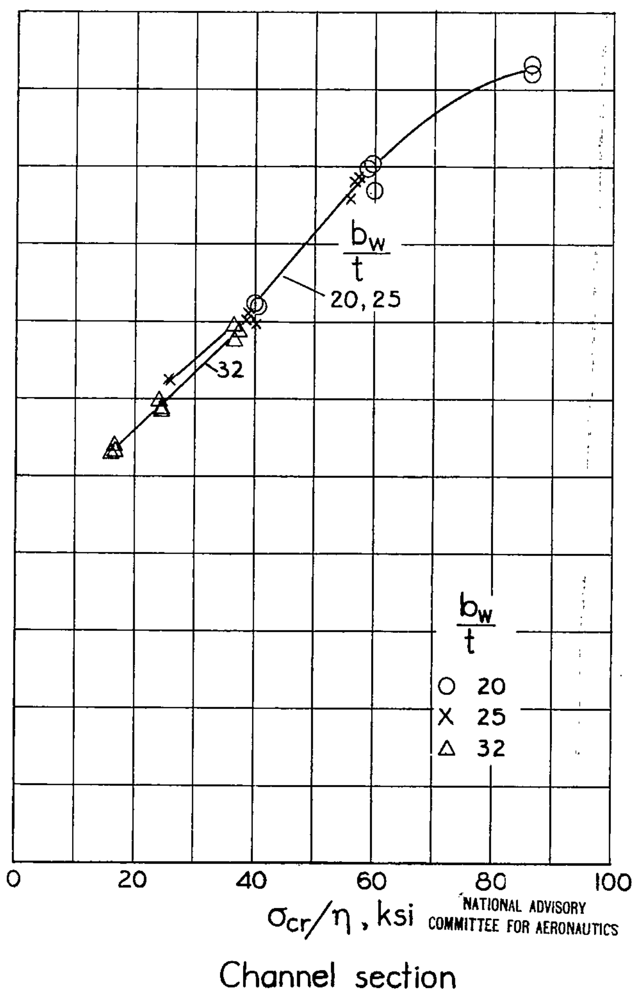


Figure 11.- Variation of $\bar{\sigma}_{max}$ with σ_{cr}/η for formed 17S-T aluminum-alloy columns loaded in the with-grain direction. $\sigma_{cy} = 41$ ksi.

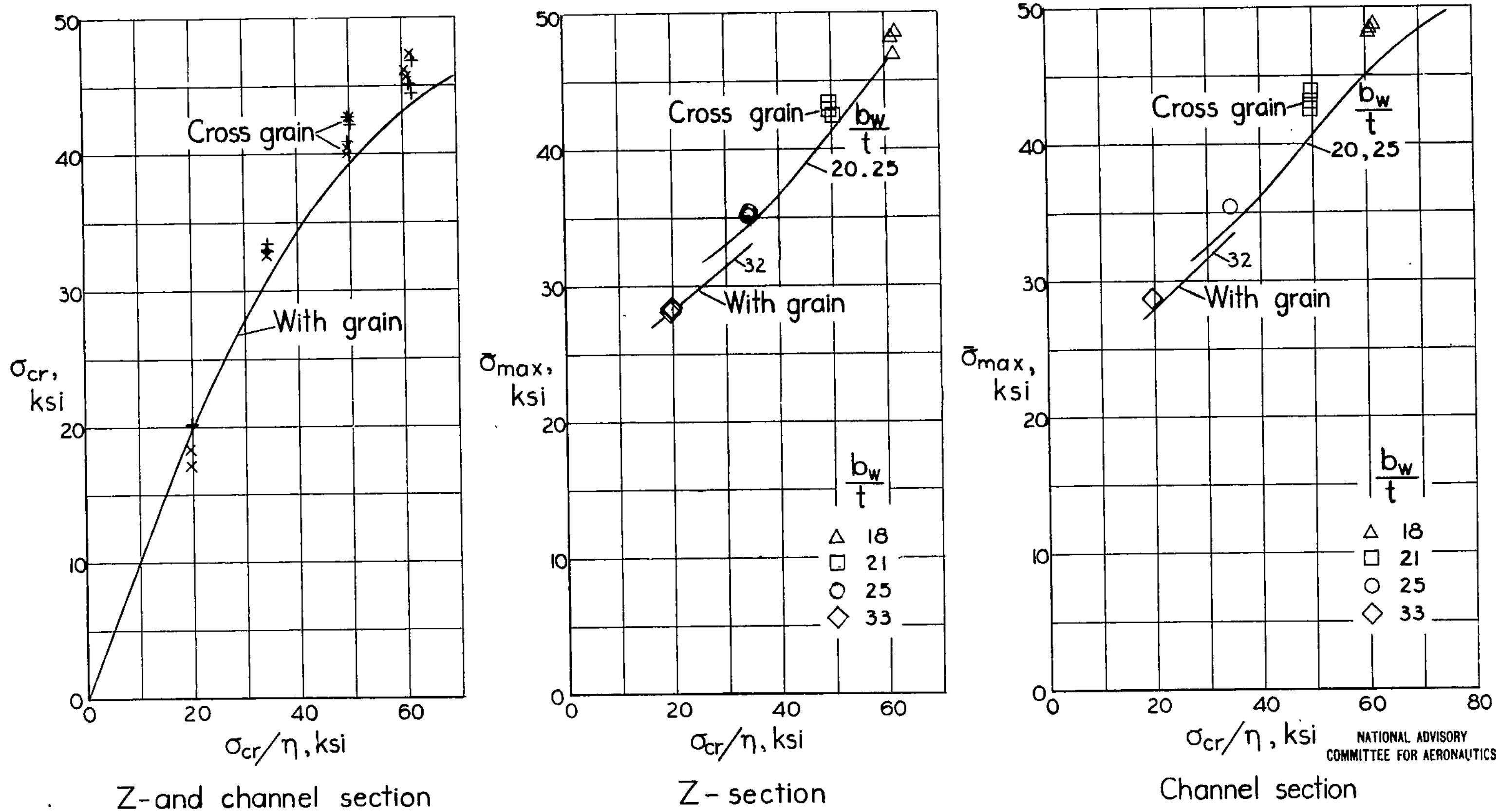


Figure 12.- Comparison of the compressive strength of formed Z- and channel-section columns of 17S-T aluminum alloy loaded in the with-grain and cross-grain directions. With-grain curves are taken from from figures 9 and 11, and test points are for the cross-grain direction.